

Moisture Deficit Effects on Cotton Lint Yield, Yield Components, and Boll Distribution

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ABSTRACT

Understanding how moisture deficit stress alters cotton (*Gossypium hirsutum* L.) reproductive growth and yield component development would provide insight into the current yield stagnation problem plaguing U.S. cotton producers. Objectives were to document the effects of moisture deficit stress on reproductive growth, lint yield, yield components, boll distribution, and fiber quality. Field studies were conducted from 1998 through 2001 utilizing eight diverse genotypes, which were grown under both dryland and irrigated conditions. Weekly white bloom counts, nodes above white bloom, lint yield, yield components, end-of-season plant mapping, and fiber quality data were collected. Genotypes responded similarly to the two soil moisture regimes for all of the parameters evaluated. Irrigation delayed cutout, the slowing of vegetative growth due to strong reproductive demand for assimilate, an average of 6 d. This delayed maturity enabled those plants to sustain flowering later in the growing season compared with dryland plants. During the years when sufficient moisture deficits occurred, the lint yield of dryland plants was reduced 25%, primarily because of a 19% reduction in number of bolls. Irrigated plants produced more bolls at higher plant nodes ($>$ Node 10) and at the more distal positions (≥ 2) on the sympodial branches than did the dryland plants. Irrigation did not affect most fiber traits, but 3 out of 4 yr of irrigation produced approximately 2% longer fiber. Production of more bolls higher up the plant and further out the fruiting branch with irrigation indicates that these areas on the plant are where high yields need to be stabilized.

LIKE MOST MAJOR agricultural crops, cotton production is negatively impacted by moisture deficit stress. While acceptable cotton yield enhancements from irrigation are prevalent in arid environments such as Arizona and California (Radin et al., 1992), the yield response to irrigation in the humid midsouthern USA remains inconsistent. This phenomenon is particularly problematic in the Lower Mississippi River Valley production region where investments have been made in irrigation equipment for approximately 50% of the production acreage.

Numerous studies over the past 40 yr have addressed how cotton yield and reproductive growth are altered by moisture deficits (Stockton et al., 1961; Bruce and Shipp, 1962; Grimes et al., 1969a, 1969b; Grimes and Yamada, 1982; Guinn and Mauney, 1984b; Kimball and Mauney, 1993; Gerik et al., 1996; Saranga et al., 1998). However, only a handful of studies have investigated how the components of yield or boll distribution were affected. Most studies only documented how moisture deficits reduced the number of bolls produced per unit ground area (Stockton et al., 1961; Bruce and Shipp, 1962;

Grimes et al., 1969a; Gerik et al., 1996). While Grimes et al. (1969a) reported that lint percentage decreased as the soil moisture level increased, Kimball and Mauney (1993) found no response in lint percentage to varying soil moisture levels. Grimes et al. (1969a) and Gerik et al. (1996) also reported that boll mass decreased in response to moisture deficits. Saranga et al. (1998) showed that drought conditions cause more motes (cotton ovules that fail to ripen into mature seeds) to be produced; therefore, one would suspect that seed formation would also be affected. With the exception of one year of data reported by McMichael and Hesketh (1982), the response of seed mass, number of seeds per boll, and the amount of lint per seed (lint index) to varying moisture levels has largely been ignored. Gerik et al. (1996) documented how moisture deficit stress altered vertical boll distribution up the main stem of the plant, but they did not address whether or not the horizontal distribution of bolls along the sympodial branches was affected.

In recent years, lint yields in the midsouthern portion of the U.S. cotton production belt have become stagnant with little or no improvement as newer varieties have been used (Meredith, 2002). Understanding how various environmental stresses impact not only lint yield but also all of the components that go into the development of that yield should provide insight into why yields appear to have plateaued. This knowledge of yield component development should demonstrate where current yields are being limited and indicate paths for future yield improvements and how to obtain superior yields more consistently.

In addition to the yield stagnation problem, there has been considerable instability in lint yield and fiber quality for some of the newer cotton cultivars currently in production. The phenomenon coincides with the increased use of transgenic cottons (Bt, containing an insect resistance gene from *Bacillus thuringiensis*; glyphosate resistant; or glyphosate resistant and Bt stacked) and weather patterns that have been hotter and drier than normal. The coupling of these phenomena has led to the speculation that transgenic cottons are more susceptible to environmental stresses than their conventional counterparts.

Gaps remain in our knowledge of how cotton grown in the midsouthern production belt responds to either adequate irrigation or moisture deficit stress. Does moisture deficit stress negatively affect transgenic cotton more strongly than conventional cotton? The objectives of this research were to assess the differences between irrigated and dryland cotton for reproductive growth and development, lint yield production, yield components, boll distribution, and fiber quality for a diverse group of cotton genotypes, including transgenic lines paired with

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Abbreviations: DAP, days after planting; NAWB, nodes above white bloom.

their conventional recurrent parent lines, in the humid midsouthern USA.

MATERIALS AND METHODS

Eight different cotton genotypes were grown under irrigated and dryland conditions from 1998 through 2001 in the field near Stoneville, MS. The soil at the experimental site was a highly productive Bosket fine sandy loam (fine-loamy, mixed, thermic Mollic Hapludalf). The genotypes evaluated were 'DPL 20', 'DPL 20B', 'FiberMax 819', 'MD 51 ne normal leaf type', 'MD 51 ne okra leaf type', 'PayMaster H1220', 'PayMaster 1220 BR', and 'STV 474'. DPL 20B contains the Bt gene that produces an endotoxin lethal to certain lepidopteran insects, and DPL 20 is the recurrent parent line to DPL 20B. PayMaster 1220 BR contains both the Bt gene and a glyphosate-resistance gene that conveys resistance to the herbicide glyphosate. PayMaster H1220 is the recurrent parent line to PayMaster 1220 BR. MD 51 ne normal leaf type and MD 51 ne okra leaf type are near isogenic lines varying in leaf shape and were provided by W.R. Meredith, Jr. Both MD 51 ne okra leaf type and FiberMax 819 possess the okra leaf type shape, which has been suggested to convey some elements of drought tolerance (Karami et al., 1980; Pettigrew et al., 1993; Voloudakis et al., 2002). The genotypes were selected to represent a range of genetic backgrounds.

Plots, consisting of four rows 7.62 m long with a 1-m spacing between rows, were planted on 23 Apr. 1998, 21 Apr. 1999, and 26 Apr. 2000 and 2001. These plots were initially overseeded and then hand-thinned to the desired population density of approximately 97 000 plants ha⁻¹. Recommended insect and weed control methods were employed during each growing season as needed. Each year, the experimental area received 112 kg N ha⁻¹ in a preplant application. The experimental area was subsoiled each fall after cotton stalk destruction.

Two soil moisture treatments (irrigated and dryland) were used. In 1998, 1999, and 2000, the irrigated plots received four furrow irrigations for a total 10.16 cm each year. Three furrow irrigations totaling 7.62 cm were applied to the irrigated plots in 2001. While the goal was to irrigate when tensiometer readings at a 30-cm depth reached 40 to 50 centibars, this schedule was adjusted (either accelerated or delayed) to accommodate required insecticide spraying and any resulting restricted re-entry interval. To enhance the degree of moisture deficit stress occurring in the dryland treatment, rainfall was prevented from entering the soil by covering the soil surface between the rows with black polyethylene film similar to the procedures described by Frederick et al. (1990). Use of this polyethylene film is estimated to prevent approximately 80% of the rainfall landing on the dryland plots from entering the soil. Land leveling of the experimental area before initiation of the experiment created enough slope in the field to allow for both furrow irrigation and rainfall to flow to the end of the field in the irrigated plots and for rainfall to flow over the polyethylene film to the end of the field in the nonirrigated plots.

Soil sampling of the experimental area at a 0- to 30-cm depth was performed approximately 48 h after a rainfall event during the winter months to estimate soil water content at approximate field capacity. Soil samples from a 0- to 30-cm depth were also collected in plots of MD 51 ne normal leaf type in both irrigated and dryland treatments during cutout (a period of slowing vegetative growth and flowering due to strong demand for assimilates by the existing boll load) to estimate the soil moisture content in the two soil moisture treatments. Both the field capacity and cutout soil samples were collected and placed in preweighed, air-tight soil tins, and the soil tins and wet soil samples were weighed immedi-

ately upon returning to the lab. Soil tins were then opened and placed in a 102°C oven for 72 h, after which they were reweighed. Soil water content was calculated from these measurements.

The experimental design was a randomized complete block with a split-plot arrangement of treatments. Five replicates were used from 1998 through 2000, and four replicates were used in 2001. The two soil moisture treatments were the main plots, and the eight genotypes comprised the subplots.

The number of white blooms (blooms at anthesis) per plot was counted on a weekly basis to document the blooming rate throughout the growing season. These counts were initiated at the first sign of blooming and were continued until production of blooms had virtually ceased. The number of main-stem nodes above a sympodial branch that had a white bloom at the first branch fruiting position (NAWB) was also counted weekly on three plants per plot to document the progressive reproductive development up the stem as well as crop maturity. Bloom counts and NAWB data were collected every year of the study.

Yield was determined by hand-harvesting the 4.6-m center section of row from one of the two inner plot rows. Four sequential hand harvests were made in 1998 and 1999 while only three harvests were made in 2000 and 2001. The number of bolls harvested per plot was counted on each harvest date. Boll mass was determined by dividing the total seed cotton harvested per plot by the total number of bolls harvested per plot. The seed cotton from each harvest was ginned to determine lint yield and lint percentage, and the resulting lint from each plot was then sent to Starlab¹ (Knoxville, TN) for fiber quality analyses. Fiber strength was determined with a stameter. Span lengths were measured with a digital fibrograph. Fiber maturity, wall thickness, and perimeter were cal-

¹Trade names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product or service, and the use of the name by USDA implies no approval of the product or service to the exclusion of others that may also be suitable.

Table 1. Monthly weather summary for 1998 to 2001 at Stoneville, MS.†

Month	1998	1999	2000	2001
precipitation, cm				
April	11.0	16.1	28.2	10.1
May	11.7	14.5	17.6	12.9
June	4.0	7.1	15.6	7.0
July	14.5	2.6	1.6	8.0
August	1.8	0.6	0.0	21.5
September	7.4	4.4	6.6	7.7
October	2.2	3.1	1.5	10.0
thermal units‡				
April	79	156	65	145
May	289	235	269	251
June	375	334	333	310
July	424	403	401	395
August	397	401	432	366
September	338	254	266	235
October	164	120	147	77
solar radiation, MJ m ⁻²				
April	544	546	513	420
May	667	703	598	559
June	733	649	619	549
July	693	712	733	546
August	626	715	690	462
September	523	547	492	399
October	453	483	460	381

† All observations made by the Weather/GIS Data Center at the Delta Research and Extension Center, Stoneville, MS.

‡ [(max. temp + min. temp.) / 2] - 15.5°C.

culated from arealometer measurements. Average seed mass was determined from 100 nondelinted seeds per plot.

At the end of each growing season, plants from 1 m of row in the inner plot row not used for yield determination were mapped for boll location. Plant height, number of main-stem nodes, node number of first sympodial branch, total number of monopodial branches, total number of monopodial branch bolls, and the main-stem node and sympodial branch position of all sympodial branch bolls were recorded.

Statistical analyses were performed by analysis of variance (PROC MIXED; SAS Inst., 1996). For traits where year interacted with treatments or genotypes and environmental effects associated with year were identified, the results were presented by year. When the treatment or genotype differences for a trait were consistent across years, then treatment or genotype means were averaged across years, and the year interactions with treatment or genotype were considered a random source of error. When statistically significant interactions were not detected, treatment means were averaged across genotypes, and genotype means were averaged across treatments. Means were separated using a protected LSD at the $P \leq 0.05$ level.

RESULTS AND DISCUSSION

Year-to-year variability among climatic factors ensured four distinct growing environments for testing the objectives throughout the duration of the study (Table 1). During the period of flowering and boll set (July and August), 1998 and 2001 received substantially more precipitation than either 1999 or 2000. Approximately 22.9 cm of rain was received during July and August in 1998 and 2001 compared with an average of 2.4 cm of rain in 1999 and 2000. The extra precipitation in 2001 was accompanied by a reduction in the solar radiation and by cooler temperatures. Because of the reduced precipitation received in 1999 and 2000, a 24% greater soil moisture deficit developed in the dryland plots during those years compared with 1998 or 2001 (Table 2).

Lint yield response averaged across years differed significantly among genotypes (Table 3). The two genotypes containing the Bt gene (DPL 20B and PayMaster 1220 BR) had the highest yields, and both were significantly higher in yield than their recurrent parent lines, indicating that some lepidopteran insect was limiting yield development of the non-Bt cotton genotypes in this study. In addition, the response to the two soil moisture regimes was similar among genotypes, demonstrating the lack of a significant genotype \times soil moisture interaction. Because no significant and meaningful genotype \times soil moisture treatment interactions were detected for any of the other traits quantified in this study, all soil moisture treatment means were averaged across genotypes.

Table 2. Soil water content (0- to 30-cm depth) at winter field capacity and at cutout in response to two irrigation regimes during the years 1998 through 2000.

Year	Soil water content (0- to 30-cm depth)		
	Winter field capacity	Cutout irrigated	Cutout dryland
	g H ₂ O kg dry soil ⁻¹ (\pm SE)		
1998	268 \pm 5	233 \pm 16	153 \pm 10
1999	264 \pm 4	186 \pm 10	121 \pm 6
2000	240 \pm 3	207 \pm 8	111 \pm 4

Table 3. Lint yield response of eight diverse cotton genotypes to two soil moisture regimes averaged across years.

Genotypes	Lint yield			Genotype mean
	Irrigated [†]	Dryland	Soil moisture difference	
	kg ha ⁻¹			
DPL 20	1111	883	228	997
DPL 20B	1192	981	211	1086
FiberMax 819	982	848	134	915
MD 51 ne normal	904	780	124	842
MD 51 ne okra	884	661	223	772
PayMaster 1220 BR	1127	970	157	1048
PayMaster H1220	1028	916	112	972
STV 474	1070	869	201	969
LSD 0.05	94	94	133	66

[†] The LSD 0.05 for the irrigated vs. dryland comparisons is 216.

Moisture deficits created by the dryland treatment consistently affected reproductive growth at almost all stages of development. Flowering was primarily affected late in the growing season when plants in the irrigated plots consistently produced significantly more blooms per unit ground area than did plants in the dryland plots during each year of the study (Fig. 1 and 2). With the exception of 1998, these blooming-rate increases were not observed until after 90 d after planting (DAP). Interestingly, in 1999 and 2001, plants in the dryland plots had significantly higher blooming rates early in the growing season compared with plants in the irrigated plots, before the increased late-season blooming developed in

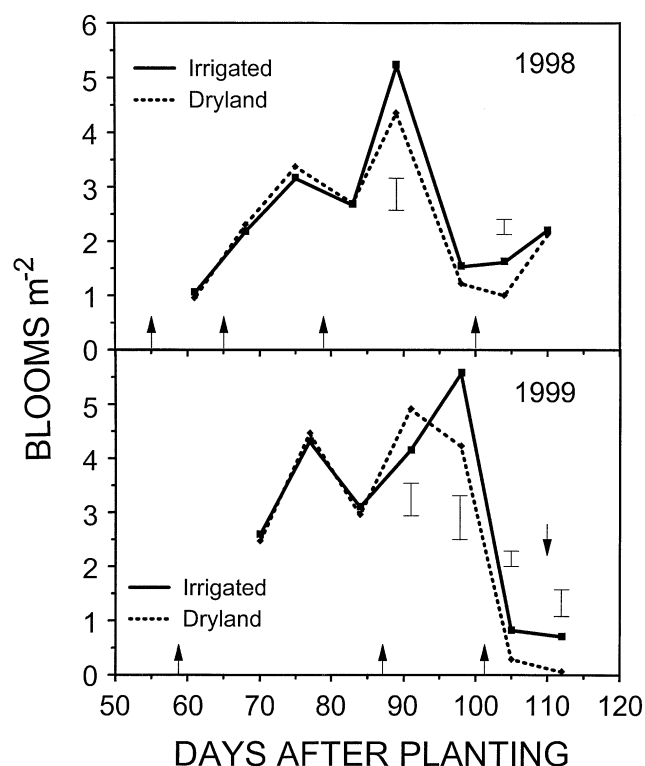


Fig. 1. White blooms (blooms at anthesis) per square meter of ground area of cotton at various days after planting throughout the 1998 and 1999 growing seasons in plots of either dryland or irrigated cotton plants. These soil moisture treatment means were averaged across eight genotypes. Vertical bars denote LSD values at the 0.05 level and are present only when the differences between soil moisture treatments are statistically significant at the 0.05 level. Dates of the irrigation events are marked by the arrows.

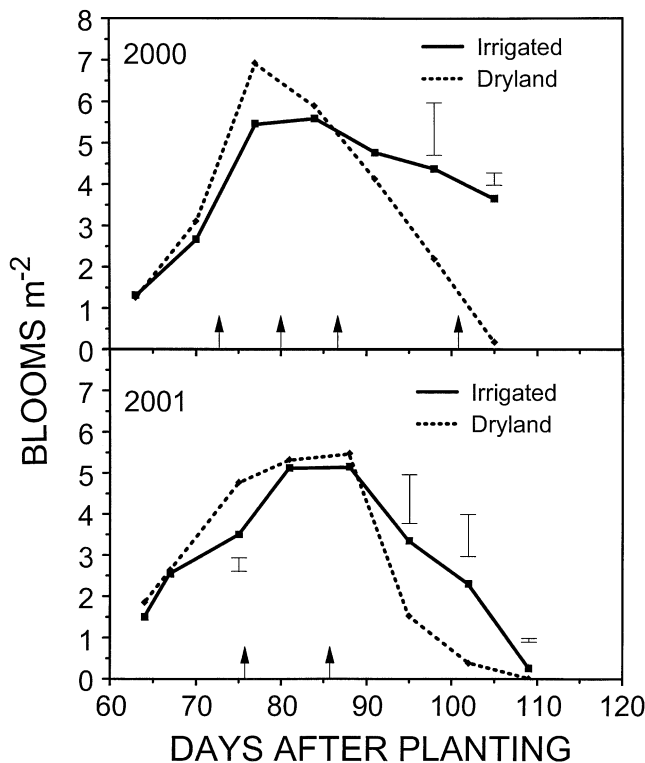


Fig. 2. White blooms (blooms at anthesis) per square meter of ground area of cotton at various days after planting (DAP) throughout the 2000 and 2001 growing seasons in plots of either dryland or irrigated cotton plants. These soil moisture treatment means were averaged across eight genotypes. Vertical bars denote LSD values at the 0.05 level and are present only when the differences between soil moisture treatments are statistically significant at the 0.05 level. Dates of the irrigation events are marked by the arrows. In 2001, an irrigation event also occurred at 57 DAP.

the irrigated plants. Similar increased early flower production under moisture deficit conditions have been reported for cotton by Guinn and Mauney (1984a). This phenomenon was inconsistently observed in their study as in this study.

Irrigated plants maintained their vegetative growth longer after the initiation of reproductive growth than did plants in the dryland treatment. This difference in plant development is demonstrated by greater NAWB counts in the irrigated plots compared with the dryland plots (Fig. 3 and 4). In 1998 through 2000, these differences were observed early and throughout much of the reproductive growth period. In 2001, the NAWB differences between the irrigated and dryland treatments did not manifest themselves until later in the growing season. Cutout has been defined for cotton growing in the Midsouth as occurring when the NAWB count declines to 5 (Bourland et al., 1992). Averaged across years, cutout occurred approximately 6 d later in the irrigated plots compared with the dryland plots (irrigated = 90 DAP and dryland = 84 DAP). These extra nodes and delayed cutout helped to sustain flowering later in the growing season for the irrigated treatment.

Irrigation increased lint yield 35% over the yields of the dryland treatment in 1999 and 2000 (Table 4). While numerically higher, irrigation did not significantly affect

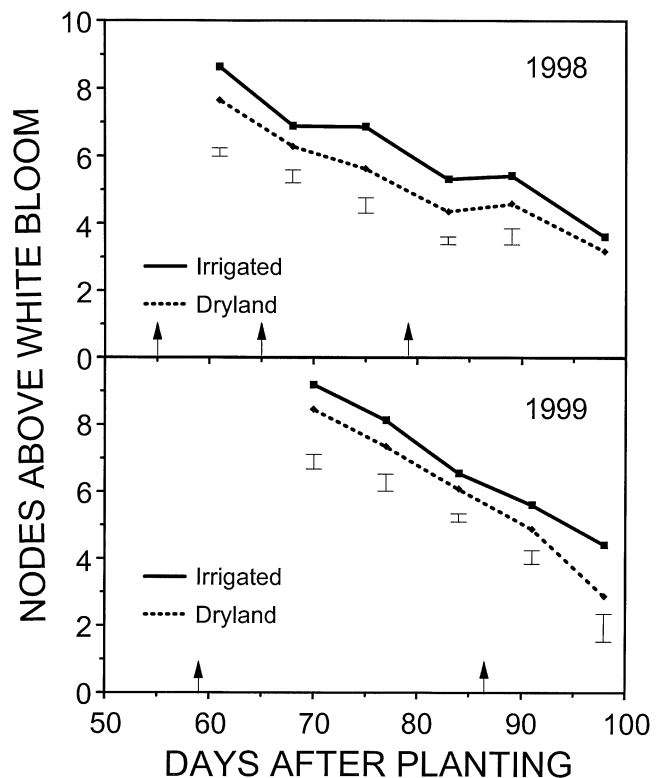


Fig. 3. Number of main-stem nodes of cotton above a sympodial branch with a first-position white bloom (bloom at anthesis) at various days after planting (DAP) throughout the 1998 and 1999 growing seasons in plots of either dryland or irrigated cotton plants. These soil moisture treatment means were averaged across eight genotypes. Vertical bars denote LSD values at the 0.05 level and are present only when the differences between soil moisture treatments are statistically significant at the 0.05 level. Dates of the irrigation events are marked by the arrows. Irrigation events also occurred at 100 DAP in 1998 and at 101 and 110 DAP in 1999.

lint yield in either 1998 or 2001 due to the additional precipitation received during flowering and boll set periods (Table 1). A 30% increase in the number of bolls produced per unit ground area resulted in this component being primarily responsible for the yield increases resulting from irrigation in 1999 and 2000. Irrigation also produced more bolls per square meter in 2001 but did not result in a significant yield increase. In 1999, irrigation also resulted in a 13% greater lint index that contributed to the higher lint yield. This greater lint index was probably because irrigation also resulted in a larger seed mass that year, implying a larger seed surface area that could accommodate more lint production. While it appears that irrigation lowered the lint percentage by 3% in 2000, caution must be used in interpreting those results due to the presence of a significant soil moisture treatment \times genotype interaction. Figure 5 shows that the majority of this lint percentage response to irrigation was produced by only two of the genotypes (FiberMax 819 and Stv 474), with the other six genotypes showing little or no lint percentage response to irrigation. Even though lint yield was improved by irrigation only 2 out of 4 yr, the maturity of the crop was delayed every year of the study. This delayed crop maturity, as demonstrated by a 31% reduc-

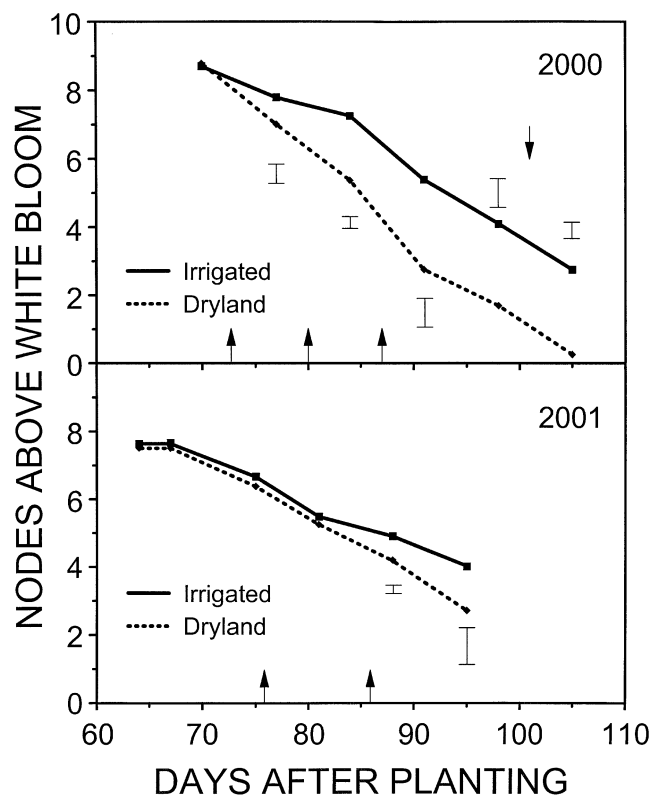


Fig. 4. Number of main-stem nodes of cotton above a sympodial branch with a first-position white bloom (bloom at anthesis) at various days after planting (DAP) throughout the 2000 and 2001 growing seasons in plots of either dryland or irrigated cotton plants. These soil moisture treatment means were averaged across eight genotypes. Vertical bars denote LSD values at the 0.05 level and are present only when the differences between soil moisture treatments are statistically significant at the 0.05 level. Dates of the irrigation events are marked by the arrows. Irrigation events also occurred at 101 DAP in 2000 and at 57 DAP in 2001.

tion in the total yield harvested on the first hand harvest for the irrigated plants compared with the dryland plants, is closely related to the delayed cutout resulting from irrigation as previously mentioned.

The fiber quality response to irrigation was inconsistent throughout the duration of this experiment (Table 5).

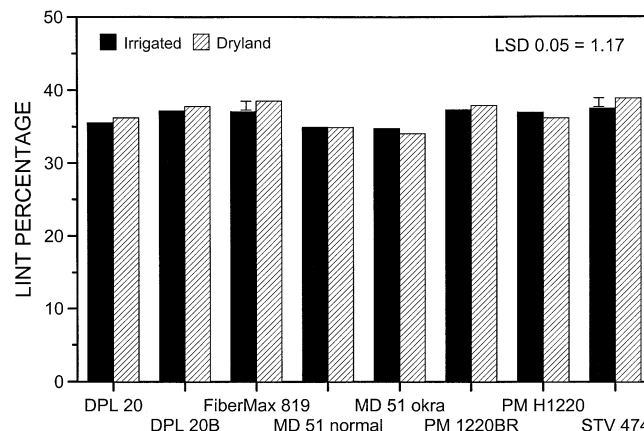


Fig. 5. Lint percentage response of eight cotton genotypes when grown under either dryland or irrigated conditions. Genotype means were averaged across the years 1998 to 2001. Vertical bars denote LSD values at the 0.05 level and are present only when the differences between soil moisture treatments for the individual genotypes are statistically significant at the 0.05 level.

Fiber length was generally shortened in response to soil moisture deficits. The 50% span length from the dryland plants was 2% shorter than from the irrigated plants in 3 of the 4 yr, and the dryland 2.5% span length was 3% shorter in 1999 and 2000. However, any irrigation effect on length uniformity was too inconsistent to be definitively assessed. Irrigation increased micronaire 11% in 1998 and 1999 but decreased it 4% in 2001. While fiber perimeter was not affected by irrigation, a 13% greater fiber maturity contributed to the higher micronaire seen with irrigation in 1999, and a 2% lower fiber maturity contributed to the lower micronaire with irrigation in 2001. Irrigation also resulted in 4% weaker fiber in 1998 and 2001 but had no effect on fiber strength in either of the other years. Fiber elongation was increased 6% with irrigation in 2000 and 2001 compared with fiber from the dryland plants but not in the other years.

End-of-season plant characteristics were consistently affected by irrigation each year of the study, and means were therefore averaged across years. Plants receiving irrigation produced 9% more main-stem nodes than

Table 4. Irrigation effects on lint yield and yield components averaged across genotypes for the years 1998 through 2001.

Year	Moisture treatment	Lint yield	Percentage first harvest	Boll number	Boll mass	Seed number	Seed mass	Lint percentage†	Lint index
		kg ha ⁻¹	%	boll m ⁻²	g	seed boll ⁻¹	mg	%	mg seed ⁻¹
1998	Dryland	795	56.2	58	3.81	23	99	36.5	57
	Irrigated	879	43.0	64	3.91	24	98	36.2	56
	LSD 0.05	ns‡	4.0	ns	ns	ns	ns	ns	ns
	P > F	0.13	0.01	0.11	0.22	0.06	0.49	0.49	0.37
1999	Dryland	794	86.1	57	3.91	28	86	36.1	48
	Irrigated	1158	55.1	79	4.09	26	95	36.3	54
	LSD 0.05	105	7.3	8	ns	ns	2	ns	1
	P > F	0.01	0.01	0.01	0.12	0.08	0.01	0.30	0.01
2000	Dryland	847	72.6	63	3.77	26	88	36.4	50
	Irrigated	1049	42.5	77	3.96	28	89	35.3	49
	LSD 0.05	113	2.8	8	ns	ns	ns	1.1	ns
	P > F	0.01	0.01	0.01	0.06	0.06	0.14	0.04	0.35
2001	Dryland	1020	73.8	59	4.68	29	97	38.2	60
	Irrigated	1063	56.8	66	4.33	27	96	37.9	59
	LSD 0.05	ns	6.2	7	ns	ns	ns	ns	ns
	P > F	0.32	0.01	0.05	0.11	0.22	0.30	0.23	0.08

† Caution should be used in interpreting irrigation means for lint percentage due to the presence of a significant moisture treatment × genotype interaction.

‡ Not significantly different at $P \leq 0.05$.

Table 5. Irrigation effects on fiber quality traits averaged across genotypes for the years 1998 through 2001.

Year	Moisture treatment	Fiber strength kN m kg ⁻¹	Fiber elongation %	Span length		Length uniformity† %	Micronaire	Fiber maturity %	Fiber perimeter μm
				2.5%	50%				
1998	Dryland	218	7.2	2.92	1.44	49.2	4.60	92.0	43.9
	Irrigated	208	7.4	2.91	1.42	49.0	4.68	92.8	44.0
	LSD 0.05	5	ns‡	ns	ns	ns	0.07	ns	ns
	<i>P</i> > <i>F</i>	0.01	0.19	0.19	0.16	0.29	0.03	0.35	0.93
1999	Dryland	212	7.4	2.88	1.41	49.1	3.53	73.0	48.0
	Irrigated	215	7.5	2.93	1.47	50.3	4.24	82.5	48.9
	LSD 0.05	ns	ns	0.03	0.01	0.7	0.12	2.1	ns
	<i>P</i> > <i>F</i>	0.18	0.27	0.01	0.01	0.01	0.01	0.01	0.06
2000	Dryland	215	7.6	2.80	1.39	49.5	3.80	80.6	45.1
	Irrigated	209	8.2	2.89	1.41	48.8	3.68	78.2	45.1
	LSD 0.05	ns	0.4	0.02	0.01	0.4	ns	ns	ns
	<i>P</i> > <i>F</i>	0.14	0.01	0.01	0.01	0.01	0.20	0.09	0.95
2001	Dryland	210	6.9	2.85	1.39	48.8	4.22	81.0	49.2
	Irrigated	206	7.2	2.90	1.42	48.9	4.07	79.1	49.3
	LSD 0.05	4	0.2	ns	0.02	ns	0.11	1.8	ns
	<i>P</i> > <i>F</i>	0.02	0.01	0.07	0.05	0.40	0.01	0.04	0.86

† Length uniformity = (50% span length/2.5% span length) × 100.

‡ Not significantly different at *P* ≤ 0.05.

plants in the dryland treatment, resulting in 20% taller plants (Table 6). While the average main-stem node number of the first sympodial branch did not differ between soil moisture treatments, the irrigated plants produced more monopodial branches per plant than did the dryland plants.

The horizontal and vertical distribution of bolls on plants was consistently and significantly affected by irrigation. Irrigation allowed the plants to set more second, third, and greater sympodial branch positions than did the dryland plants (Table 6). This horizontal distribution of bolls meant that dryland plants set a higher percentage of their total bolls as Position 1 fruit (69%) than did the irrigated plants (60%). The additional monopodial branches produced under irrigated conditions allowed those plants to bear 50% more monopodial branch bolls than the dryland plants. Irrigation also allowed plants to set more bolls on the upper plant nodes than the dryland plants (Table 7). When plants did not receive irrigation, they produced 43% fewer bolls at nodes ≥11 than did the irrigated plants. Similar number of bolls were produced by the two soil moisture regimes at nodes ≤10. The additional bolls produced higher on the irrigated plants are similar to boll distribution data in response to irrigation reported by Gerik et al. (1996).

This research determined that lint yield was reduced when soil moisture deficits got sufficiently large, which is similar to the findings of others (Stockton et al., 1961; Bruce and Shipp, 1962; Grimes et al., 1969a, 1969b; Grimes and Yamada, 1982; Guinn and Mauney, 1984b; Kimball and Mauney, 1993; Gerik et al., 1996; Saranga

et al., 1998). A reduction in the number of bolls produced per unit ground area was confirmed as the principle yield component contributing to the lint yield reduction induced by moisture deficit stress (Stockton et al., 1961; Bruce and Shipp, 1962; Grimes et al., 1969a; Gerik et al., 1996). Boll mass did not differ between soil moisture regimes in this study, whereas Grimes et al. (1969a) and Gerik et al. (1996) found smaller boll masses when moisture deficits were imposed. Lint percentage response to irrigation varied depending on the genotype. FiberMax 819 and Stv. 474 had lower lint percentage when grown with irrigation. This response is in contrast to the work of Grimes et al. (1969a), who found higher lint percentages with irrigation. Lint percentage of the other six genotypes did not change in response to irrigation, similar to results reported by Kimball and Mauney (1993). While the number of seed per boll did not vary in response to irrigation, in 1999, the moisture deficit stress on dryland plants reduced the seed mass and lint index, relative to the irrigated plants. These seed mass and lint index reductions are similar to those reported by McMichael and Hesketh (1982). The fact that some of the yield components did not respond to the different soil moisture regimes like results reported in the literature is probably because of differences in the genotypes utilized and in the degree of the moisture deficit stress that developed in this study.

Genotypes responded similarly to irrigation for all of the traits quantified, with the exception of lint percentage. This lack of significant genotype × soil moisture treatment interactions is somewhat surprising consider-

Table 6. End-of-season plant characteristics and boll distribution on sympodial and monopodial branches in response to two soil moisture regimes averaged across genotypes and years. Values were determined from plant mapping at the end of each season.

Moisture treatment	Number of plants	Plant height	Main-stem nodes	Monopodial branches	Node of 1st fruiting branch	Position 1 bolls	Position 2 bolls	Position 3 or greater bolls	Monopodial branch bolls
	plants m ⁻²	cm	nodes plant ⁻¹	branches m ⁻²	node	bolls m ⁻²			
Dryland	9.2	90	22.5	0.53	7.4	39.0	9.8	4.5	3.2
Irrigated	9.5	108	24.6	0.64	7.5	48.5	17.4	10.1	4.8
LSD 0.05	ns†	4	1.1	0.08	ns	ns	5.0	1.6	1.3
<i>P</i> > <i>F</i>	0.11	0.01	0.02	0.01	0.23	0.13	0.01	0.01	0.02

† Not significantly different at *P* ≤ 0.05.

Table 7. End-of-season boll distribution on vertical plant strata in response to two soil moisture regimes averaged across genotypes and years. Values were determined from plant mapping at the end of each season.

Moisture treatment	Total bolls	Main-stem nodal zones				
		1 to 5	6 to 10	11 to 15	16 to 20	≥21
		bolls m ⁻²				
Dryland	56.5	2.1	23.5	23.2	6.8	1.0
Irrigated	80.8	2.3	24.4	32.6	17.7	3.9
LSD 0.05	23.7	ns†	ns	7.6	ns	1.5
P > F	0.05	0.61	0.40	0.03	0.09	0.01

† Not significantly different at $P \leq 0.05$.

ing the diversity of the genotypes utilized in this study. Two of the genotypes possessed the okra-leaf trait, which other studies indicated may convey drought tolerance qualities (Karami et al., 1980; Pettigrew et al., 1993; Voloudakis et al., 2002). The two transgenic-recurrent parent genotype pairs performed similarly under both irrigated and dryland conditions. Therefore, the inclusion of transgenic traits did not make these lines more susceptible to this particular type of abiotic stress. In addition, the PayMaster 1220 genetic background is susceptible to *bronze wilt* infection, thought to be associated with high temperatures and dry conditions (Bell et al., 2002). Nevertheless, very few bronze wilt symptoms were detected in either the dryland or irrigated treatments for any of the genotypes. Despite the inclusion of these diverse genotypes, there was essentially no difference in the response of the genotype across the two soil moisture regimes.

Irrigation altered the distribution of bolls both vertically and horizontally on the plants (Tables 6 and 7). The general irrigation trend is for more bolls to be set at the higher plant nodes and further out on the sympodial branches. The production of bolls higher on the plant in response to irrigation in this study is similar to what Gerik et al. (1996) found. However, the production of bolls on more distal sites on the sympodial branches with irrigation is new information. The higher percentage of Position 1 bolls for the dryland plants explains some of the fiber quality differences between soil moisture treatments. Previous research has shown that fiber strength, micronaire, and fiber maturity increase when only a Position 1 boll remained on the sympodial branch (Pettigrew, 1995; Heitholt, 1997). Coupling these findings with the higher percentage of Position 1 bolls for the dryland plants may explain some of the unexpected fiber quality responses to irrigation, particularly the stronger dryland fiber in 1998 and 1999, as well as the higher dryland micronaire and fiber maturity in 2001.

In conclusion, the lint yield reduction caused in cotton by moisture deficit stress is primarily due to a reduction in the number of bolls produced although this stress can reduce the amount of lint produced per seed in some cases. The additional bolls that are produced under irrigated conditions are primarily located at higher plant nodes and more distal positions on sympodial branches.

The contribution that these fruiting sites make to the higher yields under irrigated conditions indicates that they are the key to high yield stability.

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